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Demonstration of a Low-Cost Monocycle Pulse for UWB Radio Transceiver

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***Abstract*—** This paper presents a simple and original method for the generation of short monocycle pulses based on the transient response of a passive band-pass filter. The recorded sub-nanosecond pulses show a good symmetry and a small ringing (13 % of the peak amplitude). Their spectral density covers the range 3.1 GHz to 10.6 GHz. The possibility to adapt the pulse spectral density to the indoor FCC frequency mask is demonstrated with a prototype working at a reduced frequency (FCC/1000). A detection technique is proposed.

***Keywords*—** Impulse, Monocycle, Transient, UWB.

I. Introduction

THE development of Ultra Wide Band (UWB) communication systems needs the generation of sub-nanosecond pulses. The realization of low-cost devices for the generation of such pulses with a power spectral density (PSD) matched to a frequency mask defined by the regulation authorities is a challenge. For instance, the range 3.1 GHZ to 10.6 GHz (bandwidth of 7.5 GHz at –10 dB) is attributed by the Federal Communication Commission (FCC) for commercial UWB devices. In this range, the maximum allowed PSD is –41.3 dBm/MHz (75 nW/MHz) [1]. Moreover, the pulse shape in the time domain is an important feature for high rate transmissions since pulses with small ringing reduce the symbol interferences. From this point of view, the monocycle is often considered as an ideal pulse shape. For instance, the model of the Gaussian monocycle corresponding to the first derivative of a Gaussian function is widely used [2]. In the literature, a few solutions are proposed for the generation of monocycle pulses, often based on integrated circuits [3, 4].

In order to propose low-cost devices for UWB applications, we explore the possibilities offered by the transient response of passive networks for short monocycle pulse generation.

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We demonstrate in this paper that pulses with the desired characteristics can be generated by this way. We have obtained experimentally sub-nanosecond monocycle pulses with a small ringing and with a PSD covering the range 3.1 GHZ to 10.6 GHz. The main convenience of symmetric monocycle pulses is to need a very simple detection scheme. This feature is demonstrated using a prototype realized at FCC/1000.

II. Principe of Monocycle Pulse Generation and Experimental Demonstration

The monocycle pulse is obtained at the output of the band-pass filter shown in Fig. 1.

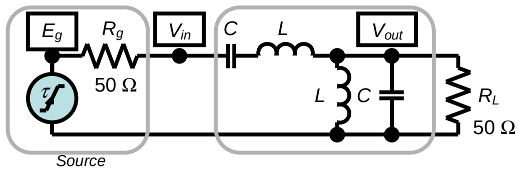


Fig. 1 The monocycle pulse generator

The capacities and the inductances have the same values. Also, the internal resistances of the source R_g as well as the loading resistance R_L are both equal to 50 Ω. The continuous transfer function is

$$M(s) = \frac{\dfrac{s^2}{\omega_0^{\,2}}}{1 + 2\cdot(\xi_1+\xi_2)\cdot\dfrac{s}{\omega_0} + 4\cdot\dfrac{s^2}{\omega_0^{\,2}} + 2\cdot(\xi_1+\xi_2)\cdot\dfrac{s^3}{\omega_0^{\,3}} + \dfrac{s^4}{\omega_0^{\,4}}} \quad (1)$$

where ω_0 is the center angular frequency of the filter given by

$$\omega_0 = 1\big/\sqrt{LC}\ . \quad (2)$$

The damping factors ξ_1 and ξ_2 are given by

$$\xi_1 \times \xi_2 = \frac{R}{2}\cdot\sqrt{\frac{C}{L}} \times \frac{1}{2\cdot R}\cdot\sqrt{\frac{L}{C}} = \frac{1}{4}\cdot \quad (3)$$

For a finite rise time τ of the source electromotive force E_g, and by choosing $\xi_{1,2} = (\sqrt{2} \pm 1)/2$, it is shown theoretically that a symmetric monocycle duration $\Delta \approx 3\times\tau$ with a minimum ringing of about 8 % of the peak amplitude is obtained for

$$\tau = 0.55\times\left(2\cdot\pi/\omega_0\right)\cdot \quad (4)$$

The adaptation to the FCC frequency mask (10 dB attenuation at 10.6 GHz) leads to choose $\omega_0/2\pi \approx 8.48$ GHz. This forces the values of passive components at $L \approx 2.26$ nH, $C \approx 0.15$ pF and the rise time at $\tau \approx 65$ ps. Fig 2(a) shows the pulse shape computed for these values. Its duration measured as the time of the first zero crossing with a positive edge is 185 ps.

We have made a prototype with the standard component values L = 1.8 nH and C = 0.2 pF. It is realized using a FR4 substrate and two SMA connectors (Photo in appendix). A step signal from an arbitrary waveform generator with a rise time τ = 65 ps was applied. Fig. 2(b) shows the experimental pulse obtained at the output of the filter. Its shape is close to the expected one with a very good symmetry and a small ringing of about 13 %. Its duration is 214 ps. The peak-to-peak amplitude is 212 mV for an input step signal of 1 V.

It is important to remark that practical realizations for UWB could use Emitter-Coupled Logic (ECL) devices as the source. Indeed, an ECL device with 70 ps typical rise and fall times is available [5]. Consequently, high data rates higher than 1 Gbit/s could be achievable with this approach.

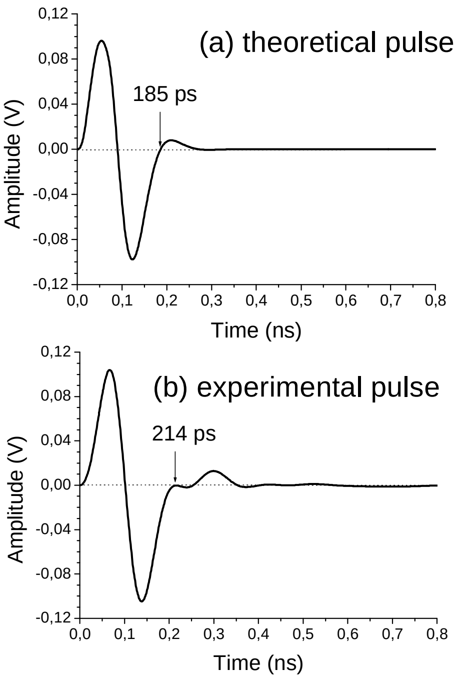


Fig. 2 The generated pulse

The PSD of the pulse is drawn in Fig. 3. The experimental spectrum is in good agreement with the computed one. It is important to note that the PSD of the ideal monocycle pulse is not adapted to the FCC frequency mask. Its bandwidth at –10 dB is 9 GHz. The adaptation to the mask needs an additional filter (notch or high-pass).

Another approach consists in changing the parameters of the circuit in Fig. 1 in order to adapt the spectrum to the mask. This will be presented in the next section.

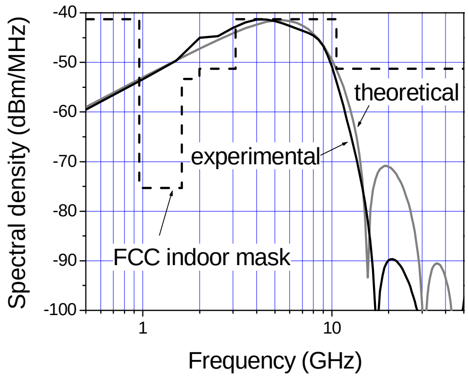


Fig. 3 PSD of the pulse

III. Adaptation to the Frequency Mask

A prototype at FCC/1000 was realized with component values chosen in order to optimize the spectrum shape between 3.1 MHz and 10.6 MHz [6]. For this purpose, the component values are L = 1 µH and C = 220 pF. The central frequency of the filter is $\omega_0/2\pi$ = 10.73 MHz. Signal V_{in} recorded at the output of the source and signal V_{out} recorded at the output of the filter are shown in Fig. 4(a). According to (4), the rise time τ is adjusted at 51 ns, corresponding to a rise time of V_{in} of 74 ns between 10 % and 90 %. The output waveform is slightly distorted compared to that of the previous section, although it keeps a good symmetry. The pulse duration is slightly shorter than in the case corresponding to the previous section (150 ns) while the ringing is slightly larger (15.4 % of the peak amplitude). The pulse amplitude is 236 mV peak-to-peak. Fig. 4(b) shows the PSD of this signal. The peak of the spectrum is found at 7.2 MHz. The FCC frequency mask for indoor UWB with frequencies divided by 1000 is also drawn in the figure. The spectrum is well-centered in the FCC mask and shows a good occupation of the allocated bandwidth. Nevertheless the peak of the spectrum is 5 dB below the frequency mask. We can notice that a ±20 % variation of τ do not change significantly the pulse shape nor the spectrum.

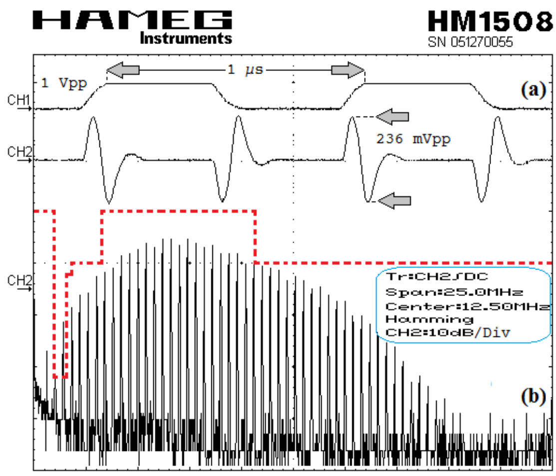


Fig. 4 (a) Experimental signals V_{in} and V_{out}
(b) PSD of the pulse sequence

IV. Detection

Those kinds of monocycles simplify considerably the detection process owing to the symmetry of the waveform. The basic architecture of the receiver is shown in Fig. 5. The first stage is a symmetric peak detector based on ECL high speed trigger circuits, directly located after the low noise amplifier. Signals (e) and (f) correspond to the detection of the positive and the negative part of the monocycle. The initial data can be found from simple logical operations between both channels.

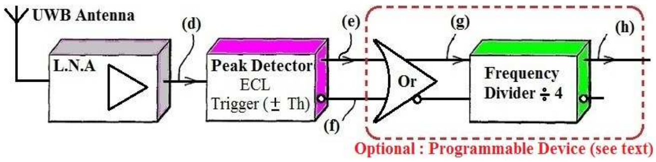


Fig. 5 UWB receiver based on ECL for monocycle pulses
(LNA: Low Noise Amplifier)

In order to demonstrate the detection process, we have realized this detector at the reduced frequency FCC/1000. The experimental signals recorded at the output of each block of the functional diagram in Fig. 5 are outlined in Fig. 6. A square signal with an additive Gaussian white noise is used as a model of the initial Non Return to Zero (NRZ) signal (c). The monocycles obtained at the output of the pulse generator described in Sec. III are applied to the input of the peak detector (d). They are compared to a positive and a negative threshold (±Th) and a pulse is generated on each channel (e) and (f). Both channels are applied to an OR gate (g) and the output is divided by 4 to recover the initial NRZ signal (h).

An optional solution to restore the initial NRZ data is to replace the circuit following the peak detector in Fig. 5 by a programmable device.

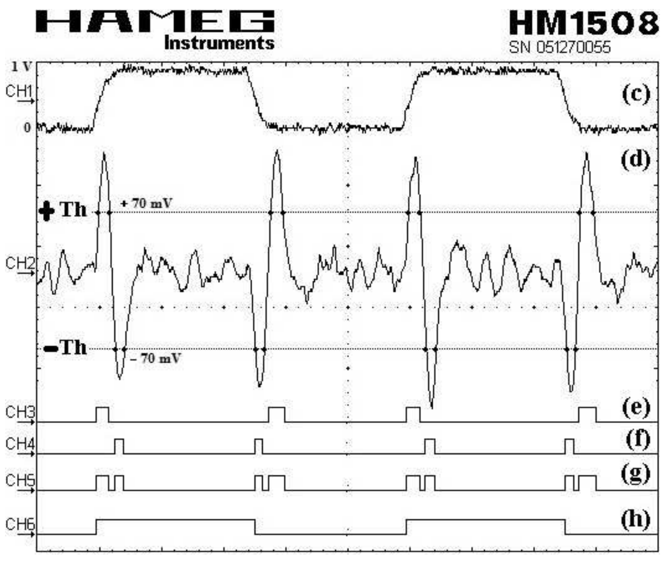


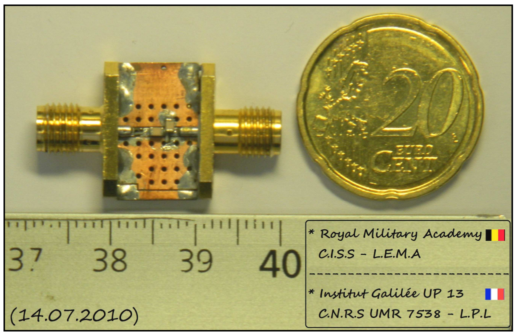
Fig. 6 Detection process

V. Conclusion

In this paper, we have described an original approach for the generation of short monocycle pulses for UWB applications. Our experimental results demonstrate that sub-nanosecond pulses with a good symmetry and a small ringing can be obtained with this approach. We have emphasized that the spectrum of the pulse at the output of the generator is not directly adapted to the FCC frequency mask. Instead of adding a filter, we have shown that the pulse spectrum could be distorted to realize this adaptation by changing the parameters of our generator. At last, the principle of a simple detection system, based on the good symmetry of the pulses is demonstrated. Low cost UWB systems for high data rate transmissions could be found on the approach presented here.

Appendix:

The prototype of the monocycle pulse generator



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